Surface quality: comparison among visual grading and 3D roughness measurements

Proceedings of The 15th International Wood Machining Seminar

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Edited by R. Szymani

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Fax: 1-925-945-0947
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Surface Quality: Comparison Among Visual Grading and 3D Roughness Measurements

G. Goli[1], P. Larricq [2], R. Marchal [3], M. Negri [4], J. P. Costes [2]
[1] DISTAF - Università degli Studi di Firenze
Via San Bonaventura 13, I-50145, Firenze, Italy
[2]INIUT – Institut Universitaire de Technologie de Génie Mécanique,
1 rue Lautréamont, 65016 Tarbes Cedex France
[3]ENSAM - Laboratoire des Matériaux et Procédés,
F-71250 Cluny, France
[4]ITL/CNR - Istituto per la Tecnologia del Legno,
Via Biasi 75, I-38010, San Michele a/A, Italy

1 Introduction

Douglas fir from fast growing plantations is an important timber resource in Europe. The huge difference within the annual rings between the latewood and early wood density affects quality of the surfaces resulting from the machining process. Nevertheless the quality of machined surfaces may be improved through a suitable machining process. To achieve this goal is necessary to describe the types, the quantities and the areas affected by the different defects on the surface of wood after it has been processed. Various methods to describe the quality of the surface were then experienced. Douglas fir specimens coming from European plantation were processed according to various grain angle; the specimens were: i) visually graded according the American standard ASTM 1666, into 5 grades and different types of defects of the standard (raised grain, fuzzy grain and torn grain); ii) analysed by a non-contact laser 3D roughness device, in order to obtain the numerical description of the whole area considered. The different methods have been then compared and discussed.

2 The Surface Quality

To understand the proper characteristics of a wood in order to be processed it is necessary to do some tests on specimens without defects, furthermore some defect can be originated artificially, with a known intensity, in order to investigate the behaviour of the material.
The quality of the timber surface resulting from a machining process can be easily evaluated through a binary judgement. This empirical method, applied by a visual grading allows few statistical data process.

By an operator, processing defects can be easily correlated with the presence of "wood defects".
By contrast, various machines able to measure the different properties describing the surface quality have been developed. The machine methods are able to measure some physical parameters more or less strictly correlated with the surface quality.

2.1 Visual Method

The machining tests have been standardised by ASTM D-1666-87. The procedures presented in this standard cover such common operation as planing, shaping, turning, boring, mortising and sanding. It includes practical methods for qualitatively evaluating and interpreting the results, through a grading method describing the quality of surfaces.

2.2 Machine evaluation

The surface quality can be evaluated by using direct or indirect methods:

- direct measures are based on mechanical and optical systems able in reproducing a surface in order to analyse it
- indirect measurements are based on principles like pressure or friction.

The most used systems are the surface analysis and the profile analysis, successfully applied for metals but that finds problems on wood because of the great variability on woodworked surfaces as magnitude and typology of defects. The most common parameters used in this kind of analysis beyond the primary profile (the measured profile of the surface) are:

- roughness
- waviness.

Primary profile, roughness and waviness are represented respectively with the capital letters P, R, W. For all these kind of profiles (roughness and waviness are obtained by filtering respectively the primary profile with a high pass and a low pass filter) sub analysis can be done and these are indicated by the letters: a, v, p, t. These letters respectively indicates the average, the deepest valley measured, the highest peak measured and the sum between the deepest valley and the highest peak. Furthermore the analysis can be done by a bi-dimensional (profile analysis) or a tri-dimensional (surface analysis) point of view. For the second possibility the letters indicating the analysis done are preceded by an s, indicating that it is a surface analysis (3D).

3 Material and Method

The aim of this work is to establish a correlation within roughness parameters and visual grading of a surface machined by a shaping machine tooled with HSS tools. Visual grading has been done according to ASTM standard D-1666-87 on surfaces obtained by cutting progressively a specimen with regular grain direction and without defects such as grain deviations or any kind of knots (see figures 2 & 3). The processed surfaces has been cut by a band saw and conserved for the roughness measurement. The specimen has been processed towards the grain and against the grain direction at different grain angles going from 0 to a max of 60 for three types of specimens (radial, tangential and intermediate).

3.1 Machining process

The surfaces have been machined by a shaping machine with the following characteristics:

i) 6500 r.p.m.
ii) manual feeding of the specimen
iii) rake angle of the knifes $\alpha = 30°$
iv) clearance angle of the knifes $\gamma = 20°$

v) HSS knifes
vi) 4 knifes mounted on the cutting head:
vii) 2 mm of cutting depth.

As described our work was oriented in two main directions: i) to put in evidence the defects originating by processing three types of specimens (radial, tangential and intermediate) at different grain angles; against the grain direction and towards the grain; ii) to compare visual examination and machine analysis of roughness profile.

To achieve the first step we used the methodology as described in Figures 1 & 2. For the second the interested section has been sawn by the mean of a band saw and conserved for the roughness analysis.

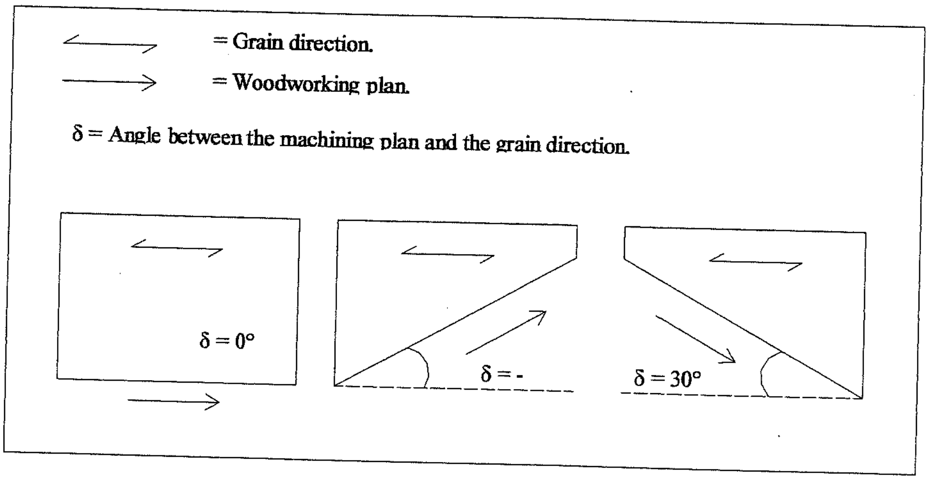

Figure 1. Methodology used to obtain different grain directions

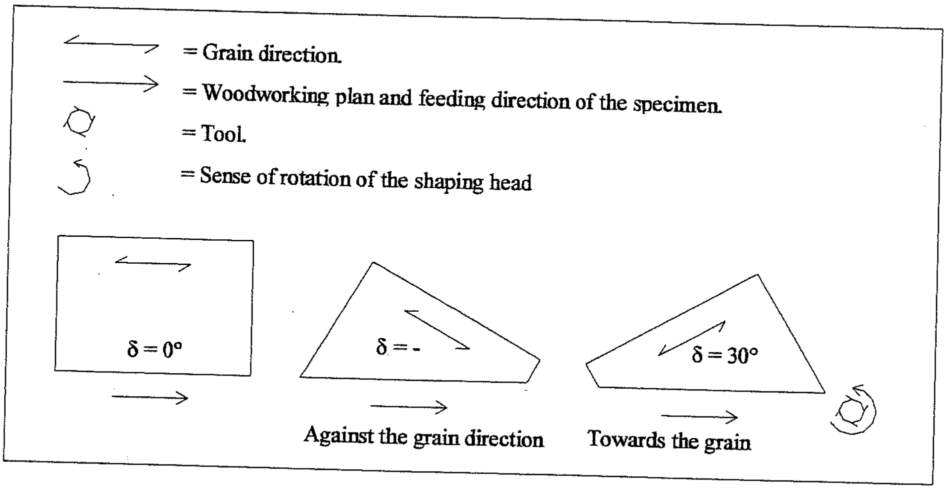

Figure 2. Methodology used to process the specimens against and towards the grain direction

3.2 Visual examination

The surface quality were classified by visual examination on the basis of five grades as defined by the considered standard:

Grade 1, excellent;
Grade 2, good;
Grade 3, fair;
Grade 4, poor;
Grade 5, very poor.

The defects classified by the standard seem to be enough for typical uses but not enough for our purposes. In effects by the definitions of every single defect we had some problems in classifying a particular state of the surface that we called Pressed Grain. This state arise from a different behaviour of the fibers towards the knife. This behaviour is slightly different from the origin of other defects. It is not reliable to fuzzy grain because the fibers do not arise over the surface or to torn grain because fibers are not torn away. In facts in Douglas fir springwood, the density is very low and it is difficult for the knife to exert a good cut if the grain it is not oriented in the cut direction because of the tendency of fibers to collapse. When the knife touch the wood, fibers are not cut and due to their low cohesion they are moved by a side leaving a groove, and they are compressed originating a very rough and rigid surface.

This type of defect is never a relevant problem. It arise sometimes around knots while working against the grain direction and often it's importance it is reduced by the presence of other defects classified as very poor, but in these tests due to the homogeneity of the surface this defect appear on the whole surface and it was not possible to classify it. For the following reasons it has been necessary to add this defect: for the difference in the originating process with any other, for it's different aspect, for the impossibility to use others defects to describe it and for its big presence.

Here follows a classification of this kind of defect (Figures 3,4,5,6).

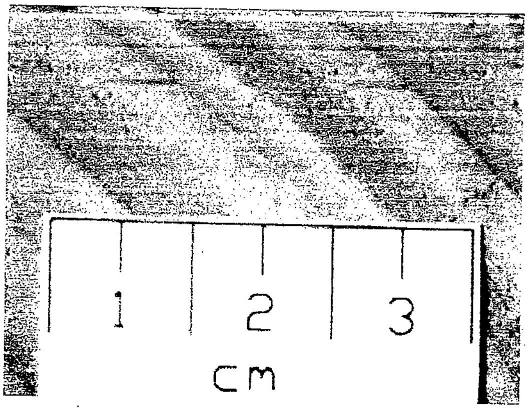

Figure 3. Pressed grain of grade 2

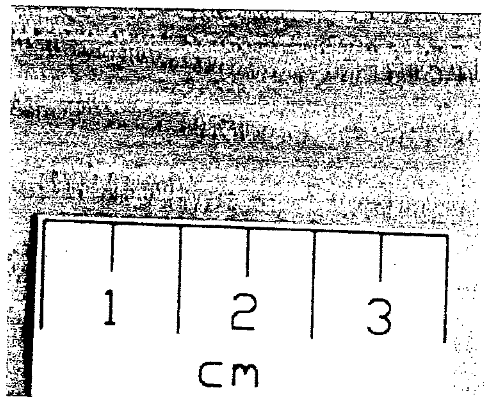

Figure 4. Pressed grain of grade 3

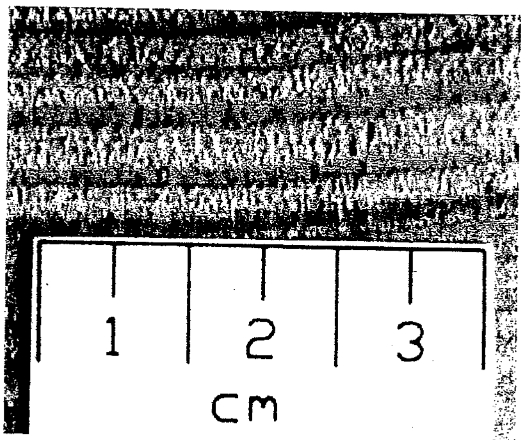

Figure 5. Pressed grain of grade 4

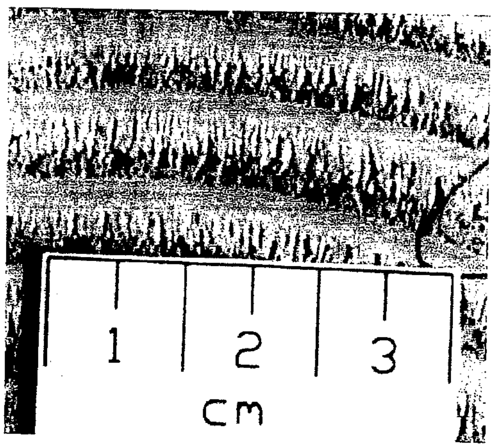

Figure 6. Pressed grain of grade 5

3.3 3D measurement system by perthometer Mahr

3.3.1 The perthometer

The measurement method by perthometer Mahr corresponds to a surface metrology unit. The equipment that we dispose enables us to take measures on a surface rather than on line, obtaining a 3D measurement that is a "surface profile". The surface is captured by a laser beam that executes a series of scans over several parallel lines. The scan is executed at a very steady rate along the measure axis, after the laser beam moves laterally for another measure. The surface is done at a different rate in the two different directions, at this approach follows different results in function of the orientation of the surface. Tests carried out to monitor this problem showed that if the surface is big enough the difference between the measures done in different directions is inside a range of 5-10 % of the measure. Preliminary tests showed that a surface of 5,6x17, 5 mm is enough to minimise this problem.

Wood shows a very high standard deviation around the mean value of roughness parameters that has been measured around 40%. This fact doesn't represent a problem for the measures but has to be considered as a characteristic of the material "wood".

Once the surface has been scanned, by the mean of a computer, the surface is reconstructed as a 3D structure building a grid in the two directions, and the parameters are computed considering the surface in its 3D structure (see Figure 7).

3.3.2 Experimental proceeding.

The equipment used is a perthometer Mahr with the following characteristics and accessories:

i) an XY table
ii) sensor: laser beam
iii) dimension of the laser beam: 2 μm
iv) Z axis length range: ±250 μm (500 μ totally)
v) number of scanned lines for every surface: 17
vi) number of scans for each line: 8064
vii) length of a line: 17,5 mm
viii) measuring area: 5,6x17,5 mm
ix) parameters acquired: sP, sR, sW
x) filter used: Gaussian.
xi)

After the acquisition the system proceed to the interpolation of scan lines aiming at recreating a three-dimensional surface. The results obtained hereafter don't represent the average of successive experiments in line but they are the result of the combined analysis of Ra on each scan line and on every transverse line considered as belonging at a single surface. The tag "s" before every parameter indicates that we are talking about a characteristic of a surface.

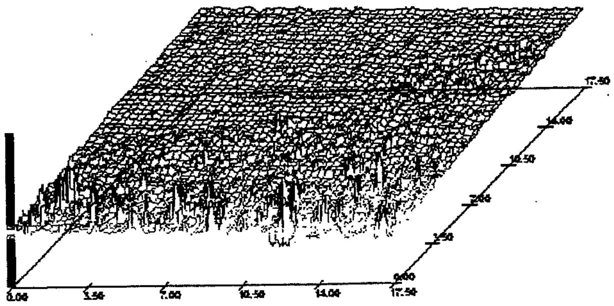

Figure 7. Example of 3D reconstructed surface

4 Results

4.1 Visual grading

First we will take into consideration the visual grading of the specimens. In the following tables, divided for anatomic direction of the fibers, is stated the results of this analysis. The machining has been possible since 60 of grain angle for intermediate and tangential specimens and since 50 for radials because of the objective danger in processing with greatest angles.

Table 1. Douglas fir specimens processed towards the grain direction in the three fundamentals anatomical directions.

	Douglas Fir specimens processed towards the grain direction											
	Tangential				*Intermediate*				*Radial*			
	Grain											
	Raised	Fuzzy	Torn	Pressed	Raised	Fuzzy	Torn	Pressed	Raised	Fuzzy	Torn	Pressed
0	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1
20	1	1	1	1	1	1	**2**	1	1	1	1	1
30	1	1	**2**	1	1	1	**2**	1	**3**	1	**2**	1
40	1	1	**2**	1	1	1	**3**	1	**3**	1	**2**	1
50	1	1	**3**	1	1	1	**4**	1	**2**	1	**2**	1
60	1	1	**3**	1	1	1	**3**	1	-	-	-	-
70	-	-	-	-	-	-	-	-	-	-	-	-
80	-	-	-	-	-	-	-	-	-	-	-	-
90	-	-	-	-	-	-	-	-	-	-	-	-

Table 2. Douglas fir specimens processed against the grain direction in the three fundamentals anatomical directions.

	Douglas Fir specimens processed against the grain direction											
	Tangential				*Intermediate*				*Radial*			
Grain	Raised	Fuzzy	Torn	Pressed	Raised	Fuzzy	Torn	Pressed	Raised	Fuzzy	Torn	Pressed
0	1	1	1	1	1	1	1	1	1	1	1	1
-10	1	3	3	1	1	3	3	2	1	1	4	1
-20	1	3	4	3	1	1	4	2	1	1	4	2
-30	1	1	1	4	1	1	3	2	1	1	5	2
-40	1	1	1	5	1	1	1	5	1	1	5	2
-50	1	1	3	5	1	1	1	4	1	1	5	3
-60	1	1	4	5	1	1	1	3	-	-	-	-
-70	-	-	-	-	-	-	-	-	-	-	-	-
-80	-	-	-	-	-	-	-	-	-	-	-	-
-90	-	-	-	-	1	1	5	4	-	-	-	-

These results are summarised in the following figures considering the worst class of defect found for every grain angle.

4.2 Machine grading

Of the parameters furnished by the perthometer we take into account only the sR for many reasons:

i) the parameter sW considering the waviness of the profile take into account even the washbording produced by the normal work of the tool, matter we are not interested in at this time because we look only by processing defects classified by the mentioned standard;

ii) the parameter sRp take into account both the sR and the sW, and as mentioned it is not in our desires to consider sW;

iii) after some correlations between visual grading worst defect and by the other side sPa, sRa, sWa, we have seen that as supposed the best correlation was with the sRa.

We analysed the typical parameters: sRa, sRp, sRv, sRt. Some of these parameters sometimes were out of range because of the great irregularities of the surfaces analysed. Thus it has been impossible to use the parameters sRp and sRv. The parameter sRt has been kept into account because anyway it gives indications about the great irregularity characterising a surface even if out of range.

It is not in the matter of this paper to make a comparison between the usefulness of the parameters acquired (sP, sR, sW) anyway maybe useful to begin the results chapter by giving a brief idea of how these factors are linked for passing steady at the sRa analysis.

4.2.1 Comparison between sRa, sWa, sPa and visual grading

Here follows a brief analysis of the various parameters for tangential specimens processed towards the grain direction and against the grain direction. Note how in both cases the correlation

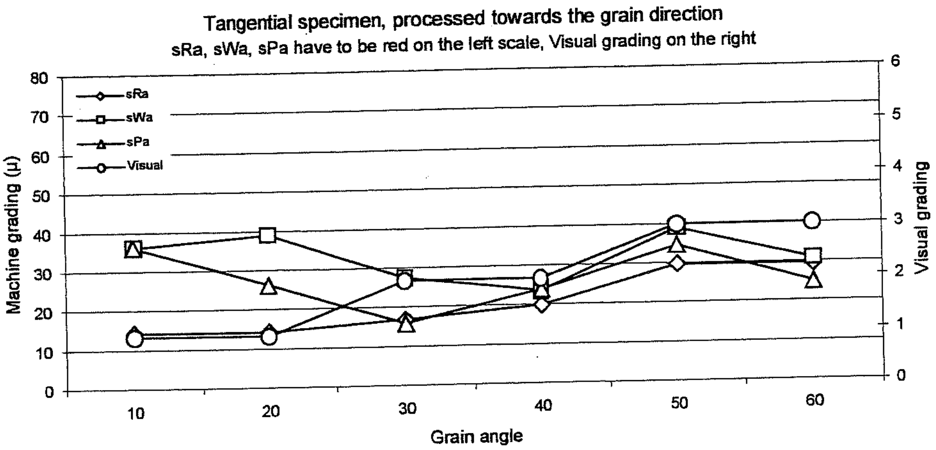

Figure 8. Comparison between sRa, sWa, sPa, and Visual grading curves for a tangential specimen processed towards the grain direction.

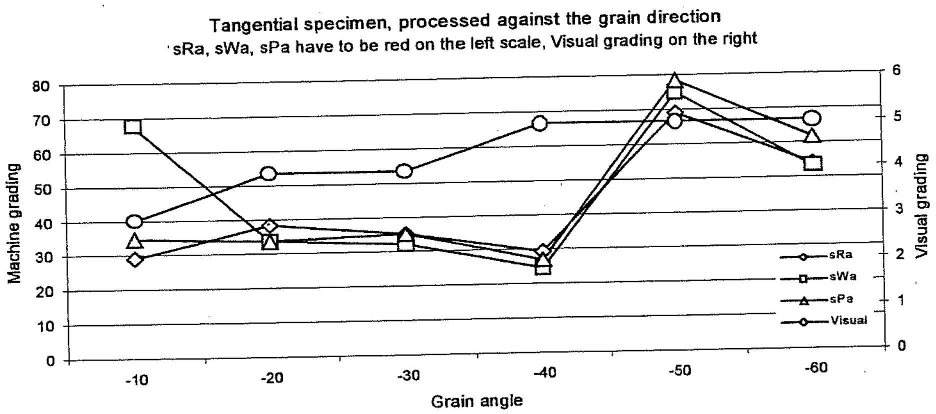

Figure 9. Comparison between sRa, sWa, sPa, and Visual grading curves for a tangential specimen processed against the grain direction.

between the sR parameters and the worst defect considered in visual grading are strongest then for other parameters.

As previously explained it is not in the matter of this paper to analyse these factors, then we pass directly to the sRa analysis.

4.2.2 Comparison between sRa and visual grading

Stated the sRa as the comparison parameter, it is necessary to understand what can be used as reference in visual grading. For easiness we chosen the way of the worst defect found on the surface considering all the defect typologies, for every grain angle. It is sure that every defect acts in a different way on roughness parameters but synthetic indexes needs to be of easy calculation.

4.2.2.1 Machined towards the grain direction.

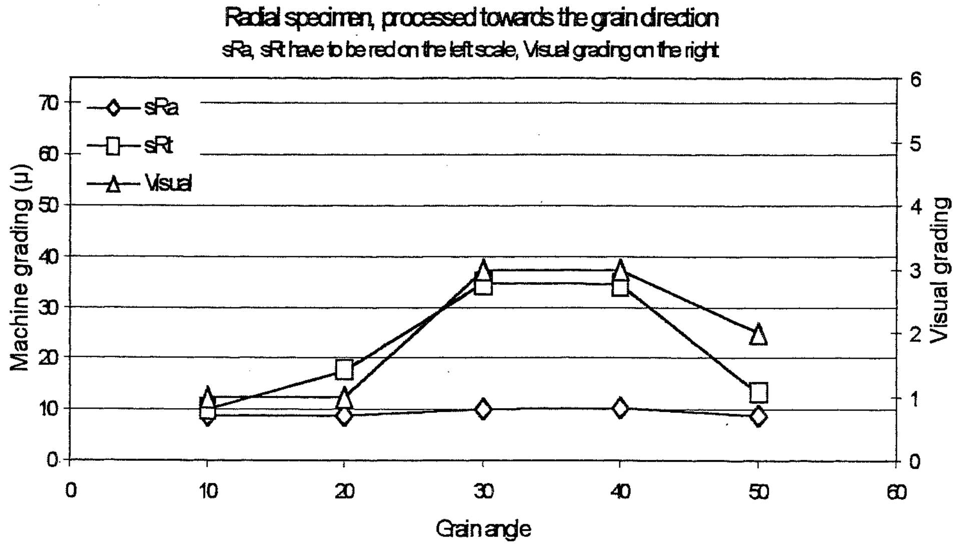

Figure 10. Analysis of sRa, sRt and Visual grading curves for a radial specimen processed towards the grain direction. sRt is divided by 10 to be comparable with other values.

Radial: in radial specimens the most important defect is the torn grain, but it is never a relevant defect (grade 3 and 4 of visual grading). The torn parts are not diffused over the whole surface, then or they stay out of the measuring area or we have a dilution of these valleys by the presence of a very good surface in the rest of the measured area. For these reasons the sRa is low (8-10 μ) even if perfectly superposed to visual grading. Rt do not arrive at relevant levels even if in the worst sections it arrive to approx 35 μ.

Intermediate: in this case it is easy to see how the general situation is worse then for radial. This is well indicated even from the sRa parameters, with a peak on the 50° specimen were roughness is very high and sRt is very high too. For low angles roughness is low (14 μ) but sRt is higher then

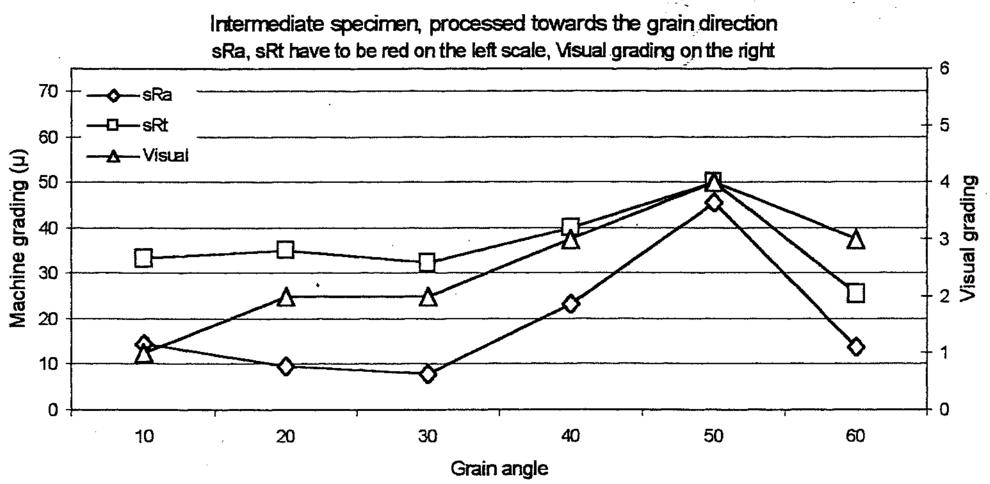

Figure 11. Analysis of sRa, sRt and Visual grading curves for an intermediate specimen processed against the grain direction. sRt is divided by 10 to be comparable with other values.

before, confirming the good quality of the radial specimens. Even in this case the sRa is well correlated with visual grading. Note how at 40, where the surface arrives to grade three in visual grading the roughness increases very much and passes the 20 µ for increasing more, and even sRt goes up arriving out of range (the value sRt has to be multiplied by 10 in order to obtain the real value).

Tangential: we can always see a good correlation between sRa and visual grading. For smooth angles are less clear the behaviour of sRt. Even in this case passing from grade 2 to 3 leads to a rise of sRa from 20 µ to 30 µ. sRt with the increase of the angle goes out of range, shoving a bad surface.

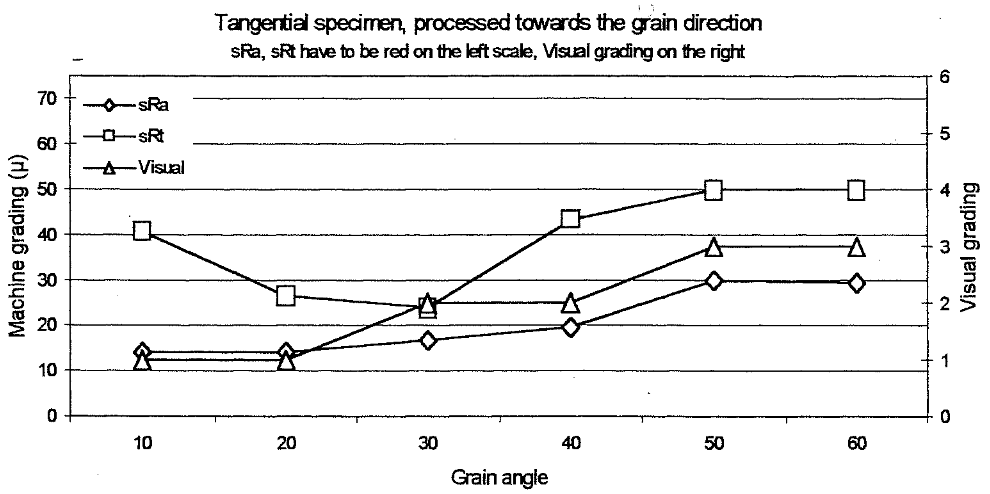

Figure 12. Analysis of sRa, sRt and visual grading curves for a tangential specimen processed towards the grain direction. sRt is divided by 10 to be comparable with other values.

4.2.2.2 Machined against the grain direction.

Radial: it has been impossible to measure these surfaces because of the high grade of defects (torn grain 4 and 5). The measuring system was permanently out of range. It shows anyway a surface of very bad quality.

Intermediate: in this case visual grading never gets down the grade 3. Even in this case visual grading and sRa are well correlated with high values of sRa and sRt, showing a very bad surface since narrows angles of the grain

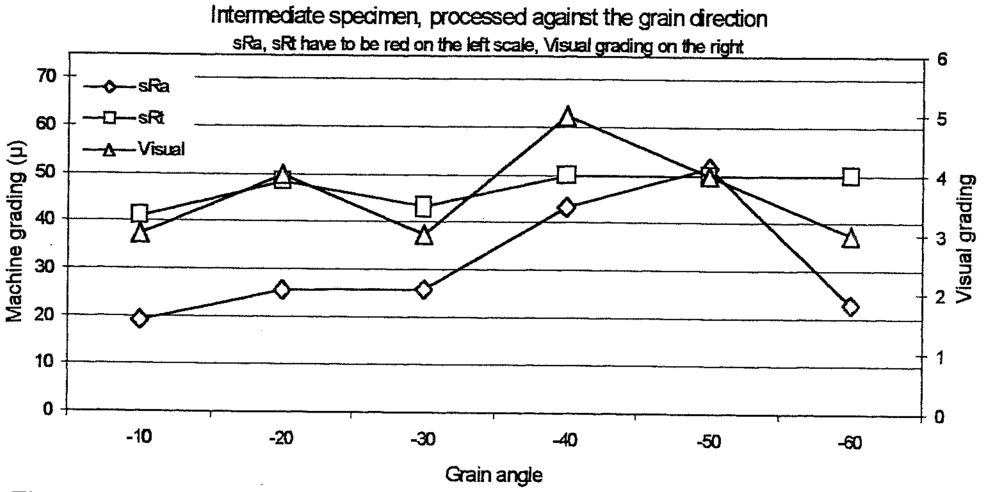

Figure 14. Analysis of sRa, sRt and Visual grading curves for an intermediate specimen processed against the grain direction. sRt is divided by 10 to be comparable with other **values.**

Tangential: the lowest roughness value is around 30 μ; it indicates a very bad surface quality, as shown from visual grading. sRt almost permanently out of range confirms our suppositions based on the sRa values.

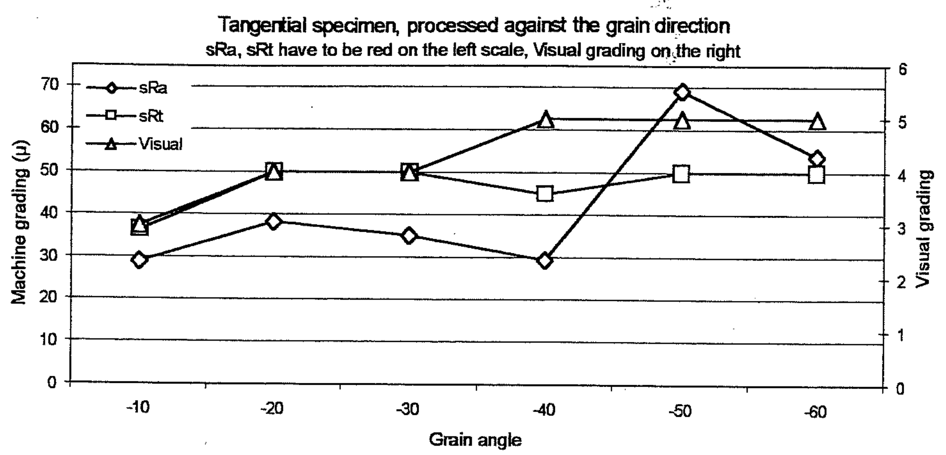

Figure 15. Analysis of sRa, sRt and visual grading curves for a tangential specimen processed against the grain direction. sRt is divided by 10 to be comparable with other **values.**

5 Discussion and Conclusions

The differences of surface quality on wood processed by turning tool (in this specific case Douglas Fir) are depending on the grain direction. Great differences of surfaces are obtained processing wood at different grain angles and towards the grain direction or against the grain direction. Different results are obtained even in processing with the same conditions of cut specimens with different anatomical directions.

Surfaces processed against the grain are always worse then who's processed in the grain direction and the quality grade decrease increasing the grain angle. Towards the grain direction the best quality is obtained by processing radial specimens, because the early wood (very low density in the Douglas fir) that normally tend to be torn have the great support of the late wood. In the intermediate the early wood have less support then it tend to be torn a little more away, for this reason the quality decrease, since the tangential specimens were the early wood it is not supported at all and great defects arise. Surfaces processed against the grain direction are in general worse than who's processed towards the grain. The worse are the radial because of the tendency of late wood not to be cut, but it is pressed against the early wood that collapsing leads the formation of deep fractures in the late wood, and then great portions are torn away. In order of final quality after radial specimens we found the tangential specimens, before the intermediate because of the reasons just explained analysing the process towards the grain direction.

A brief comparison between visual grading (intended as the worst defect affecting the surface), sR, sW, sP showed sR as the parameter in best correlation with visual grading. Moreover considering the typical parameters of roughness (sRt, sRv, sRp) we found sRt as a very useful datum to understand the quality of the surface if considered together with sRa. Very interesting could be the ratio between sRp and sRv to understand if the surface has been processed towards the grain or against the grain, in facts in the first case the surface is flat with many valleys, in the second case even if there is more torn grain, fuzzy grain and pressed grain play an important role on the peaks importance. Data have not been analysed by this side because of the permanent out of scale of these parameters in the analysis of the surfaces processed against the grain (peeks and valleys exceeded 250 μ, and the sum was major than 500 μ).

Summarising by this experience we can say that:

1. visual grading is a rapid and complete way to analyse the quality of woodworked surfaces;
2. the ASTM standard gives a complete way for surfaces analysis;
3. the use of a 3D surface roughness analysis done by a perthometer seems to give some data well correlated with the results of a visual grading done following the ASTM standard;
4. the most suitable parameter to take into account between sR, sW and sP for comparison with visual grading seem to be sR. sP has some aspects similar to visual grading (considered as the worst defect found on the surface), while sW seems to be completely inadequate to be correlated with visual grading;
5. in roughness analysis the most useful parameters seems to be sRa and sRt. About sRp and sRv unfortunately we can not give conclusions because of the out of scale (> than 250 μ) of the instrument on the surfaces processed against the grain direction;
6. the surfaces machined towards the grain directions are much better then those processed against the grain, and the level of the parameters sRa and sRt make immediately clear this fact;
7. towards the grain direction radial specimens are those who have given the best results as surface property, followed by the tangential and the intermediate with a final quality not far. This tendency is supported even from visual grading than from roughness analysis;
8. against the grain direction intermediate and tangential specimens are those who have given the best results as surface property, followed by radial to be considered the worst. This tendency is supported even from visual grading than from roughness analysis;
9. the presence of a fully unacceptable surface (a surface where same defect has been graded as 3 with visual grading) is often indicated by an sRa value around or higher then 20 μ and an sRt over 40 μ.
10. the use of a perthometer with an out of scale highest than 500 μ could give some interesting data about sRp and sRv;
11. The parameters sRa and sRt are very useful in understanding the quality of a surface.

6 References

1. ASTM D-1666. 1987. Standard methods for Conducting Machining Tests of Wood and Wood -Base Materials, Annual Book of ASTM Standards, Volume 04.09 Wood, pp. 257-276.
2. Petrocchi S. 1984. Prove di lavorabilità e di abrasione degli utensili su alcune specie legnose. Tesi di laurea, Università degli Studi di Firenze, Facoltà di Agraria, corso di laurea in Scienze Forestali.
3. Negri M, Goli G. 2000. Qualità delle superfici lavorate del legno di Abete rosso e di Douglasia valutata con una opportuna classifcazione visuale, Legno Carta e Cellulosa, VI(1), pp 10-21.
4. Precision Devices, Inc. Surface Metrology Guide, http://www.predev.com/smg.
5. Goli G, Negri M, Marchal R, and P. Larriq. 1997. The machining process of the European Douglas fir: the surface quality, Proceedings of the 3rd International Conference on the Development of Forestry and wood Science/Technology, pp. 473-480.